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cc: Peter

# Technical Memorandum

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Div. of Oil, Gas & Mining

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**To:** Mike Forbush
**From:** Scott Effner, P.G.
**Date:** September 8, 2011
**Subject:** **Bosshardt Mine Subsidence - August 24 Trip Report**

The following memorandum presents recommendations for the evaluation and mitigation of subsidence related to groundwater inflow at the Bosshardt Salt Mine, near Redmond Utah. The mine is owned by Redmond Minerals (Redmond) and operated during the 1980s. The underground workings have been allowed to flood and are being used as a brine source for the mill. Surface subsidence began in June 2011 and is currently active. Agapito Associates, Inc. (AAI) has been retained by Redmond to evaluate the collapse and provide recommendations to limit future subsidence. AAI is also preparing an assessment of the feasibility of future underground mining beneath the collapsed area. Whetstone Associates, Inc. (Whetstone) has been retained by Redmond to evaluate hydrologic factors contributing to the collapse and recommend mitigation strategies to reduce or eliminate groundwater inflow to the underground workings.

## Site Inspection and Meeting

On August 24, 2011, Leo Gilbride (AAI) and Scott Effner (Whetstone) met with Mine Engineer Mike Forbush and other Redmond personnel to discuss subsidence above the Bosshardt Mine, review the site, and tour the active underground workings located north of the subsiding area. The meeting included discussions about the underground workings and mining methods, geology, observed groundwater inflow and water handling practices, recent subsidence, and plans for future mining. The underground tour provided an opportunity to view the salt characteristics, fracturing, and inflow to the active mining area. Surface subsidence areas were also inspected during the tour to provide background information about the extent and nature of the collapse.

## Background Information

The following background information is summarized from the AAI Trip Report and discussions during the August 24 site visit.

The Bosshardt Mine is located on the apex of the Redmond Hills salt diapir. The salt beds strike north-south and dip vertically. The diapir is approximately 900 feet (ft) wide near the mine. The salt beds are overlain by Quaternary-age alluvium. The alluvium contains groundwater and is greater than 20 feet thick in some areas. A stiff clay layer is generally present between the alluvium and the underlying salt.

The Bosshardt pit was mined to a depth of about 150 ft and extended several hundred feet along the strike of the diapir. Portals were developed near the base of the pit in the east and west highwalls. Underground workings extend north and south from the portals. At least one tunnel was developed beneath the pit. The sill below the pit floor (prior to collapse) was about 60 ft thick. Tunnel dimensions generally range from 40 to 60 ft tall and 40 to 80 ft wide. The tunnel below the pit is estimated to be up to 150 ft wide. No maps of the historical workings are available. The footprint of the underground workings as shown in the AAI Trip Report is approximate and is based on recollections of the personnel who worked in the mine during the late 1980s. Most of the Bosshardt underground workings are believed to be on a single level with the exception of superimposed tunnels south of the Bosshardt mine ventilation shaft. The tunnels ramped downward and the deepest part of the mine is believed to be located below the collapsed pit.

The Bosshardt Pit encountered groundwater inflows during mining and is the wettest location along the diapir mined to date. Inflow to the pit occurred from the base of the alluvium along the western highwall. Shallow gravel-filled channels were incised into the top of the salt at some locations. Examples of the channels were viewed during the site visit and the channel morphology is consistent with erosion by water flowing along the surface of the salt beds. In contrast, the underground workings for the North mine extend within 800 feet of the Bosshardt Pit and are dry.

A French drain was installed at the base of the alluvium along the western edge of the open pit to intercept shallow groundwater during mining. Discharge from the drain averages about 15 gpm and originates from farmland areas located to the west. Flows from the drain have been observed to increase during periods of active irrigation. The drain effectively controlled groundwater inflow as mining transitioned to an underground operation during the 1980s. Figure 1 in the AAI trip report shows the approximate location of the French drain.

At the end of active operation, the mine was allowed to flood and a well was installed in the floor of the pit to provide brine for the mill. The well intercepted the underground workings and withdrew water directly from the mine at a rate of about 10,000 gallons per week (1gpm average). The water level in the mine has risen at a rate of few feet a year and is currently stable at about 20 feet below the pit floor. This level is above the base of the crown pillar for the underground workings.

At some time prior to 2000, the discharge valve for the French drain was closed and the drain system was rendered inoperative. Shortly after eliminating the discharge, mine personnel noted sinkholes forming on the east side of the French drain. The sinkholes are likely caused by the dissolution of salt by shallow groundwater as it flowed across the top of the diaper.

Discharge from the French drain was re-established in 2008 and piped into the into the east portal of the underground working. Although the flow from the drain (15 gpm) exceeds the rate of withdrawal for the mill (1 gpm), the water level in the underground mine has remained relatively stable. This water balance suggests that a flow path has been established through the salt into the alluvium or sedimentary rocks on the east side of the diaper.

Discharge from the French drain is relatively fresh water containing about 3% NaCl by weight (14% saturation). Brine from the underground workings is reported to be near saturation at about 25% NaCl by weight.

## Hydrologic Evaluation

Based on observation of the surface topography, alluvial thickness and extent west of the Bosshardt Mine, and characteristics of the salt in the adjacent North Mine, inflow to the underground workings in the Bosshardt Mine appear to originate primarily from shallow groundwater flowing along the alluvial contact with bedrock. As a rule, the permeability of salt formations is exceptionally low.

Published literature generally cites hydraulic conductivity values that range from $10^{-12}$ to $10^{-10}$ cm/sec. Fractures or faulting may increase permeability, however, deformation in salt is usually ductile and fracturing is often sealed by salt precipitation unless the fractures are exposed to unsaturated groundwater flow, in which case, rapid dissolution and piping may result. Review of the underground workings in the North Mine did not indicate significant permeability in the salt. The permeability of the salt in the Bosshardt Mine area could be higher than observed at the North Mine, however, my initial impression is that it is likely negligible as well. Further testing and evaluation would be required to confirm this impression.

Groundwater flowing at the base of the alluvium originates from the farmland and hills west of the mine. The topography on the west side of the diapir slopes east and is gently rolling, forming a surface water drainage that crosses the diapir in the area of the Bosshardt Mine. It is likely that the topography of the top of bedrock is similar, forming subsurface a low that directs shallow groundwater flow toward the mine. This conclusion was likely the original design basis for the French drain.

Shallow groundwater flow patterns have been modified by excavation of the pit and installation of the interceptor system. Prior to mining, alluvial groundwater crossed the diapir on the clay layer at the top of bedrock. After mining, the groundwater flow path was interrupted and was either removed by the French drain or flowed in to the underground workings during periods that the discharge line for the French drain was closed. Movement of unsaturated water into the underground working resulted in dissolution of the salt and the creation of sinkholes.

Given the density differences between freshwater and brine, dissolution was likely most active at the surface of the mine pool and moved outward from the point of inflow along the underground workings until it established a point of outflow on the east side of the diapir either in a fractured zone in the bedrock or possibly in the alluvium. The location of the outflow point is unknown, but it is probable that it is at an elevation near the current mine pool level given that water levels are stable.

## Recommendations

Redmond has expressed interested in renewing mining operations in Bosshardt Mine area at deeper levels within the diapir. There is also concern that ongoing subsidence could impact the mill. Historical inflows to the mine area have occurred from shallow groundwater in the alluvium and it is probable that the salt has low permeability and will not transmit appreciable volumes of water. This assumption, however, should be tested by the installation of several piezometers along the strike of the deposit prior to the development of detailed mining plans.

Whetstone recommends that groundwater flow paths in the alluvium be evaluated to determine hazard areas for future subsidence and to facilitate mine planning. Given that flow paths are believed to follow topographically low areas on the bedrock surface, it is recommended that a geophysical survey be performed along the western margin of the diapir to delineate the top of bedrock. This will allow for evaluation of the effectiveness of the existing drain and for determination if additional interception systems are required. Our initial inquiry with Chinook Geoconsulting of Evergreen, Colorado suggests that magnetotellurics (MT) or electromagnetics (EM) may be appropriate geophysical methods for the study.

Whetstone also recommends that alluvium on the eastern side of the diapir be evaluated using the same geophysical methods to determine the topography of the bedrock and to investigate whether a brine plume can be detected. The information would be used to evaluate hazard areas for future subsidence, and to evaluate potential for contamination of nearby surface water and groundwater resources.

Finally, it is recommended that discharge of water into the mine workings be avoided, and if possible, discharge from the French drain should be routed to the eastern side of the diapir or other area away from the salt for disposal. It is not recommended that flow from the drain be stopped by closing the valve on the discharge line. It is probable that closing the valve will result in unsaturated groundwater bypassing the interceptor system and entering the mine pool through established subsurface seepage pathways.